Director's Annual Review

LBNL Physics Division

November 5–6, 2003

Theory Group

- Overall Status / Description of the Group
- Research: Femtoreviews

  Flavor Physics Topics

Zoltan Ligeti

LBNL staff & UCB faculty

LBNL Senior Staff: Barnett (PDG/ATLAS), Cahn (BABAR), Chanowitz[1],
Hinchliffe (ATLAS)

LBNL Divisional Fellow: Ligeti

UCB Faculty: Bardacki, Bousso (1/04), Gaillard[2], Ganor, Hall[3], Halpern,
Horava, Murayama[4], Nomura, Suzuki

Retired: LBNL: Stapp
UCB: Chew, Jackson, Mandelstam, Zumino

Support staff: Planka, Lockhart (60%)

[1] Group Leader
[2] Acting NSF PI
[3] Theory Center Head
[4] NSF PI, sabbatical @ IAS

Group operates as a single unit

Utilizing pooled resources:

- LBNL Physics Division (DOE)
- UCB theory grant (NSF)
- UCB Theory Center
  - UCB endowment ($1M "seed")
  - LBNL 5-yr ops support (~ 300k$/yr)

Allocate resources to:

- Postdocs
- Students
- Visitor program
- Seminars:

"ecumenical"	Monday	alternates
"strings"	Tuesday	campus
"4-d"	Wednesday	LBNL

Postdocs

Significant expansion in FY ’04 (default is 2 LBNL + 3 NSF) due to

Theory Center	+3
UCB Miller Fellow	+1
Ligeti DOE–OJI	+1

Converted 3 postdocs to 5-year fellows

Continuing:

G. Burdman

Z. Chacko (5 yr $\longrightarrow$ Arizona, 8/04)

W. Goldberger

M. Rangamani

R. Tatar

M. Perelstein (5 yr $\longrightarrow$ Cornell, 8/03)

FY ’04 additions:

E. Gimon (5 yr, from IAS)

I. Mitra (from Princeton)

G. Perez (from Weizmann)

M. Schwartz (from Harvard)

T. Watari (Miller, from Tokyo)

Students

GSRA's supported for two years:

– LBNL 6

– Center 2

Current Roster:

A. Birkedal-Hansen (MKG) $\longrightarrow$ Florida
E. Boyda (PH)
D-W. Chiou (OG)
S. Ganguli (PH)
J. Gill (OG)
R. Harnik (HM)
C. Helfgott (MH)
B-S. Kim (OG)
D. Larson (HM)
T. Okui (LH) $\longrightarrow$ Boston U
S. Oliver (LH)
I. Osipenkov (MKG)
C. Park (MKG)
A. Pasqua (BZ)
M. Randsdorp (OG)
U. Varadarajan (BZ) $\longrightarrow$ U of Texas
D. Vasilyuk (OG)

Visitor Program

Name	Dates	Home Institution
Drukker, Nadav	11/2/02 – 11/6/02	Weizmann Institute
Ramgoolam, Sanjaye	11/15/02 – 11/16/02	Brown University
Armoni, Adi	11/16/02 – 11/24/02	CERN
Ooguri, Hirosi	12/3/02 – 12/9/02	Caltech
Leibovich, Adam	2/2/03 – 2/7/03	Fermilab
Wise, Mark	2/6/03 – 2/9/03 4/4/03 – 4/6/03	Caltech
Narayan, Krishnan	2/10/03 – 2/16/03	Duke University
Hiller, Gudrun	3/3/03 – 3/17/03	LMU, Munchen
Luty, Markus	3/18/03 – 3/30/03	U. of Maryland
Graesser, Michael	3/24/03 – 4/11/03	Caltech
Grojean, Christophe	3/24/03 – 4/11/03	CEA/Saclay
Guralnik, Zachary	3/30/03 –4/12/03	Humboldt University
Katz, Emmanuel	4/4/03 – 4/22/03	U. of Washington
Sharpe, Eric	4/20/03 – 4/24/03	UIUC
Harmark, Troels	4/28/03 – 5/8/03	Harvard
Terning, John	5/7/03 – 5/16/03	LANL
Thorn, Charles	5/21/03 – 5/31/03	U. of Florida
Mitra, Indrajit	5/25/03 – 5/31/03	Princeton
Falkowski, Adam	6/15/03 –7/13/03	Warsaw University
Lazaroiu, Calin	6/16/03 – 6/22/03	Humboldt U. of Berlin
Ko, Pyungwon	8/11/03 – 8/17/03	U. of Michigan
Piai, Maurizio	8/17/03 – 8/30/03	Yale University

Supports 1–3 week visits:

- Foster joint research with group members
- FY ’03 & ’04 funding from Center

Outlook

Despite fiscal hard times, Physics Division and LBNL Directorate have strongly supported HEP theory:

- Big LBNL role in faculty recruitment/retention
- Reduction of LBNL postdocs ($4 \to 2$) reversed by support of Theory Center
- Limited resources affect recruitment/retention; e.g., unfavorable comparisons to Harvard and Stanford theory centers, with which we are in direct competition
- Director has responded with funds to begin renovation of LBNL theory area; Plans proceed for space for Theory Center in renovated building on campus

LBNL theory staff:
- diminished by redirection of effort
- unfulfilled mandate from previous panels to recruit senior theorist or/and division fellow

Theorists share division-wide concerns over effects of impending space crunch which coincides with big increase in size of the group

Research Interests

Traditionally strong in both particle physics and formal theory

Faculty hires to revitalize formal theory:

Fall '01:	Ganor, Horava
Winter '04:	Bousso (Asst. Prof.)

Particle physics:

- New hire Fall '03: Nomura (Asst. Prof.)
- Strong center of model-building and of theory closely related to experiment
- Close coupling to experimental program, e.g.:
  - Cahn, Ligeti, Murayama participated in inter-divisional ν study group
  - Ligeti interacts with Division's B Physics programs @ BABAR & CDF
  - And we have made the ultimate sacrifice:

    Cahn $\longrightarrow$ BABAR

    Hinchliffe $\longrightarrow$ ATLAS

Involvement in planning experimental program

LBNL neutrino working group (PD, NSD, AFRD)

Cahn, Ligeti (deputy chair), Murayama

Super-B-factory workshops

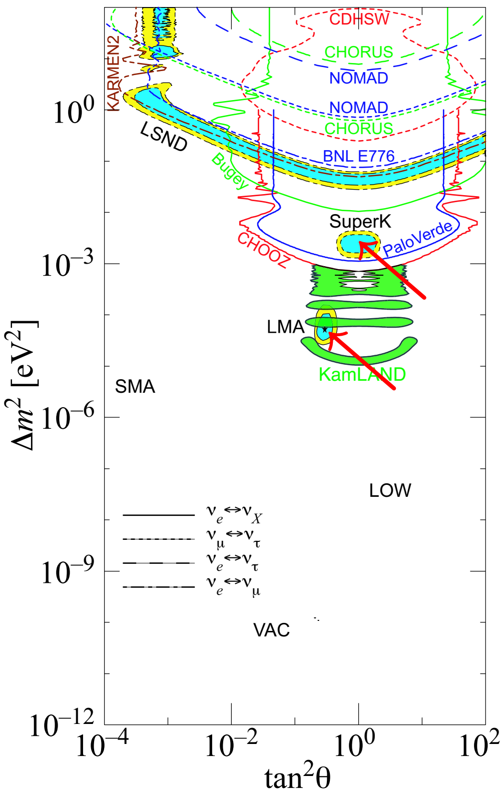
Cahn, Ligeti (conveners); Burdman, Perez

Neutrino Working Group

[Cahn, ZL, Murayama]

Coherent planning effort across PD, NSD, AFRD (16 members)

Charge: “survey the theoretical landscape and recent experimental results” “which will be the most compelling next set of neutrino experiments world-wide” “lay the groundwork for development of proposals ... for support of our work”



Recommendations being implemented:

- Initiative for reactor-based experiment to measure θ_{13} (PD, NSD $\Rightarrow$ Heeger’s talk)
- Neutrinoless $\beta\beta$ decay:
  - New LBNL involvement in Majorana (NSD)
  - LDRD for Cuore (NSD, MSD) and Majorana (NSD)
  - LDRD for R&D for an insulating liquid TPC (PD, LLNL)

Super-B-factory workshops

[Burdman, Cahn, ZL, Perez]

BABAR: Workshop on the Discovery Potential of an Asymmetric B Factory at 10^{36} Luminosity (May 8-10, Oct. 22-24)

BELLE: Workshop on Higher Luminosity B Factory (5th: Sep. 24-26)
$\Rightarrow$ LOI by end of the year

Physics case for a high luminosity B factory? Identify measurements that do not become theory limited $\Rightarrow$ better sensitivity to new flavor physics:

- CP asymmetry in $B \to \phi K_S$ and related modes to < 0.05
- Rare decays: inclusively and with ν's ($B \to X_s \ell^+ \ell^-,\ K^{(*)} \nu \bar\nu$)
- Precise measurement of γ from $B^\pm \to D K^\pm \to f_i$
- Precise determination of α using $B \to \pi^0 \pi^0$, maybe $\rho\rho,\ \rho\pi$
- Several measurements of $|V_{ub}|$ at 5% level

Extra–Group service, etc.

- Barnett: Quarknet co-PI; ATLAS education coordinator
- Cahn: APS POPA
- Chanowitz: Phys. Div. staff committee chair
- Gaillard: consultant to National Science Board
- Hall: Director, Center for Theoretical Physics
  Plenary talk on new physics at EPS'03
- Hinchliffe: Organizing commitee for ATLAS physics workshop in Athens
- Ligeti: Organizing committee, "$|V_{xb}|$ and $|V_{tx}|$ — workshop on semileptonic and radiative rare B decays," at SLAC
- Murayama: Fermilab PAC, Neutrino Facilities Assessment Committee (National Research Council), Executive Committee to American Linear Collider Physics Group, HEPAP Cosmos Committee, DPF Executive Committee
  Concluding talk at LP 2003, plenary talk on neutrino physics at EPS 2003

Sampling of Physics Topics

Cahn & Jackson: $D_s(2317)$, $D_s(2458)$ masses and widths not explicable assuming Coulombic vector potential

Chanowitz: precision EW data and the limit on m_H: problems of SM fit not resolved by assuming syst. error; Signature of scalar glueball decay

Hall: extra-dimension scenarios, e.g., extra-dim. GUT solution to “classical” GUT problems; 5-d SUSY with natural TeV-scale SUSY breaking; θ_W from TeV-scale 5-d quark-lepton unification

Hinchliffe: SUSY signals at LHC

Ligeti: flavor physics, e.g.: method to extract CKM angle γ; determination of m_b and $|V_{cb}|$ from semileptonic B decay; SU(3) relations to test SM prediction for CPV in $B \to \phi K_S$, etc.

Murayama: broad program, e.g., model building: Higgs as component of extra-dim. gauge fields, Technicolorful Supersymmetry; neutrinos: scenarios for $0\nu\beta\beta$ and θ_{13}, WMAP + 2dF GRS contradict LSND, connection to $B \to \phi K_S$ in GUTs; CMB anisotropy from scalar field baryogenesis

Suzuki: proposals for determining the quantum numbers of the new narrow D_s and $X(3872)$ states by analyzing various decays

Sampling of Physics Topics (cont.)

Bardakci: study field theories using world sheet techniques of string theory, e.g., world sheet formulation of large-N ϕ^3 field theory as prototype for string formulation of QCD

Gaillard: connecting Planck-scale string theory to SUGRA, GUT, and TeV-scale physics, e.g., gaugino condensation in the presence of an anomalous $U(1)$

Ganor: strings, M-theory, extra-d field theories, e.g., nonlocal interactions from D-branes in plane-wave backgrounds; gravity in nonlocal theories and possible significance for the early universe

Halpern: large-N limit of conformal field theory; Studies of WZW orbifolds

Horava: string theory/M-theory and cosmological implications, e.g., holographic protection of chronology in string theory cosmologies with closed time-like curves ("Godel-type")

Zumino: noncommutative Yang-Mills theories, e.g., construction of Seiberg-Witten maps; covariant quantization method for off-shell superparticle in 10-d

Summary

- Theory group has strong programs in both particle physics and formal theory
- Theorists are closely linked to LBNL experimental program
- New LBNL theory appointments essential to
  - maintain viability of theory at LBNL
  - maintain balance with campus theory effort

Part II: Flavor Physics

Recent B factory results

BABAR and BELLE are doing beautiful unexpected stuff:

- Discover narrow D_s states [Cahn, Jackson; Suzuki]
- Discover narrow $c\bar{c}$ state [Suzuki]
- Experiment sometimes ahead of theory, e.g.:
  - BABAR's $B \to \rho\rho$ analysis (LBNL $\Rightarrow$ Borgland's talk) [ZL]
  - BELLE's $B \to K^+K^-K_S$ analysis [ZL]

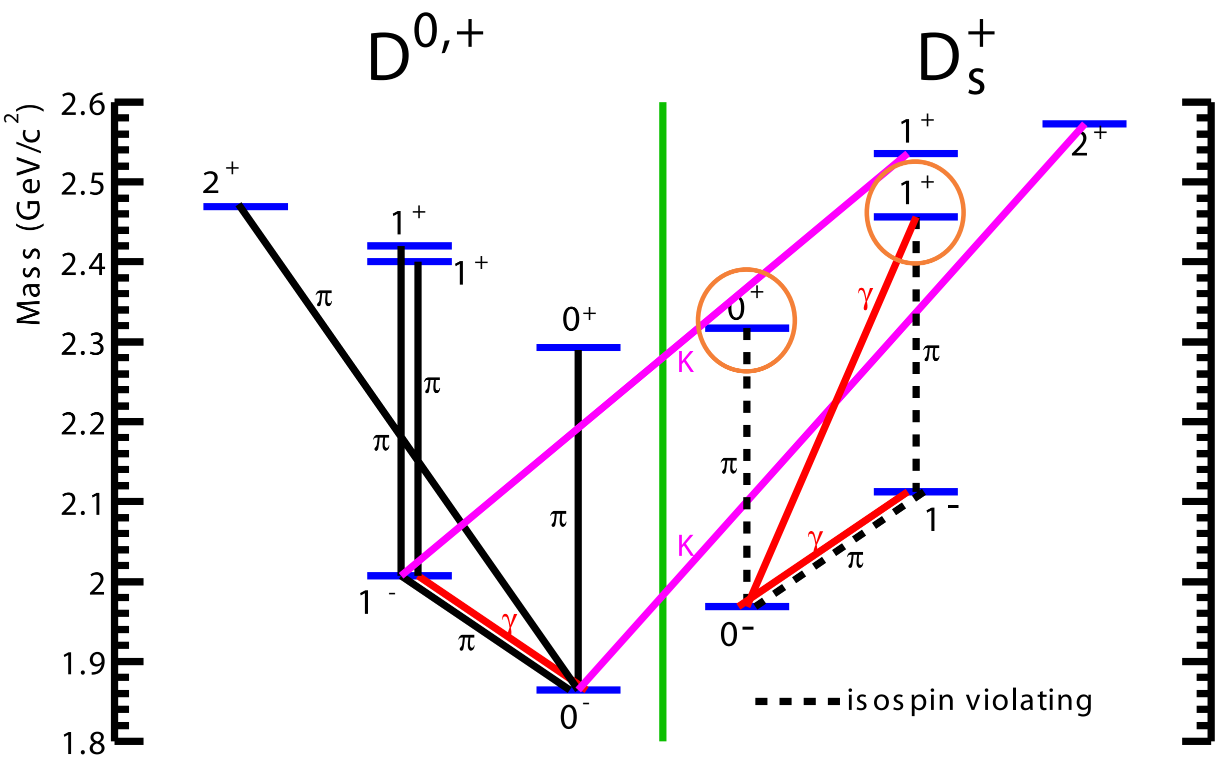
Real surprises — we are learning new things about Nature

Possible hints also of the kind of surprises people had hoped for:

- 2.7σ deviation from SM in $B \to \phi K_S$ (2.2σ in $B \to \eta' K_S$) [see later]
- Longitudinal polarization near 1 in $B \to \rho\rho,\ \rho K^*$, but about 1/2 in ϕK^*
  (need to understand theory better before concluding)

New narrow D_s states

[Cahn, Jackson; Suzuki]



BABAR / CLEO / BELLE:

$D_s(2317)$, probably 0^+

$D_s(2458)$, probably 1^+

$4\ L=1$ states: $s_\ell^{\pi_\ell} = \frac{1}{2}^+,\ \frac{3}{2}^+$

$\frac{3}{2}^+$ are well-known, narrow

Ground state: $0^-,\ 1^-$

- What are these states? Potential models predicted ~ 150 MeV heavier masses
- Need to understand masses and widths (mixing with 1^+, $s_\ell^{\pi_\ell} = \frac{3}{2}^+$ state small)
- Why splitting from non-strange counterparts so small?

CP asymmetry in $B \to \phi K_S$

- Sensitive to new physics in $b \to s\bar{s}s$ flavor changing neutral current
- Strongest present hint for new physics (2.7σ)
- A reason to consider a super-B-factory (flavor violation possibly not accessible at LHC)
- Many of us worked on it from different angles

R. Harnik, D. T. Larson, H. Murayama and A. Pierce: *"Atmospheric neutrinos can make beauty strange,"* hep-ph/0212180

Y. Grossman, Z. Ligeti, Y. Nir and H. Quinn: *"SU(3) relations and the CP asymmetries in B decays to $\eta' K_S$, ϕK_S and $K^+K^-K_S$,"* Phys. Rev. D **68** (2003) 015004 [hep-ph/0303171]

G. Burdman: *"Flavor violation in warped extra dimensions and CP asymmetries in B decays,"* hep-ph/0310144

Time-dependent CP violation

- CPV in interference between decay and mixing
  Especially interesting if both B^0 and $\overline{B}{}^0$ can decay to same final state, e.g., $|f\rangle = |f_{CP}\rangle$:

$$\begin{tikzcd} B^0 \arrow[rr, "\text{decay}"] \arrow[dr, "\text{mixing}"'] & & f_{CP} \\ & \overline{B}{}^0 \arrow[ur, "\text{decay}"'] & \end{tikzcd}$$

$$a_f(t) = \frac{\Gamma[\overline{B}{}^0(t) \to f] - \Gamma[B^0(t) \to f]}{\Gamma[\overline{B}{}^0(t) \to f] + \Gamma[B^0(t) \to f]} = S_f \sin(\Delta m\, t) - C_f \cos(\Delta m\, t)$$

$$\lambda_f = \frac{q}{p}\,\frac{\overline{A}_f}{A_f} = \eta_f\,\frac{q}{p}\,\frac{\overline{A}_{\overline{f}}}{A_f} \qquad S_f = \frac{2\,\mathrm{Im}\,\lambda_f}{1+|\lambda_f|^2} \qquad C_f = \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2}$$

  If $|\lambda_f| \neq 1 \;\Rightarrow\;$ CPV in mixing and/or decay; usually hard to interpret

  If $|\lambda_f| \approx 1 \;\Rightarrow\;$ CPV in interference; clean information on a CPV phase possible

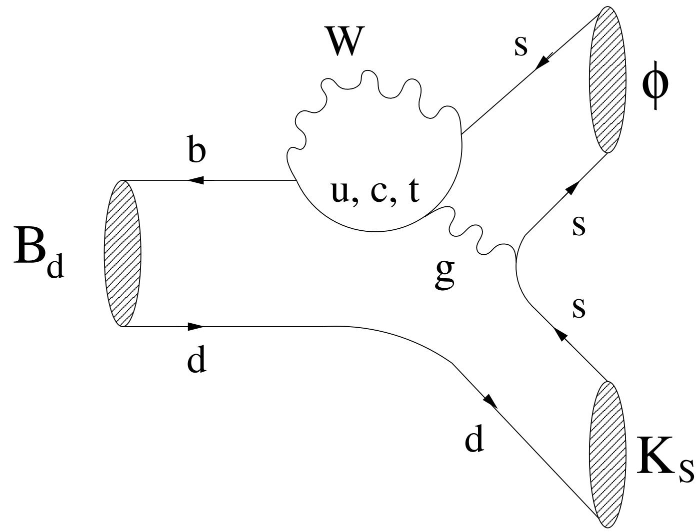
- If amplitudes with one weak phase dominate a decay then CP asymmetry cleanly measures a phase in the Lagrangian

New Physics and CPV in ϕK_S

- Several contributions to the decay amplitude:

$$A = \overset{\mathcal{O}(\lambda^2)}{V_{tb}^* V_{ts}}\, P_t + \overset{\mathcal{O}(\lambda^2)}{V_{cb}^* V_{cs}}\, P_c + \overset{\mathcal{O}(\lambda^4)}{V_{ub}^* V_{us}}\, P_u$$

$+$ **New Physics?**



In the SM: $V_{tb}^* V_{ts} + V_{cb}^* V_{cs} + V_{ub}^* V_{us} = 0$

$\Rightarrow$ a single phase dominates

expect $S_{\phi K_S} \approx S_{\psi K}$ to $\mathcal{O}(\lambda^2) \sim 0.05$

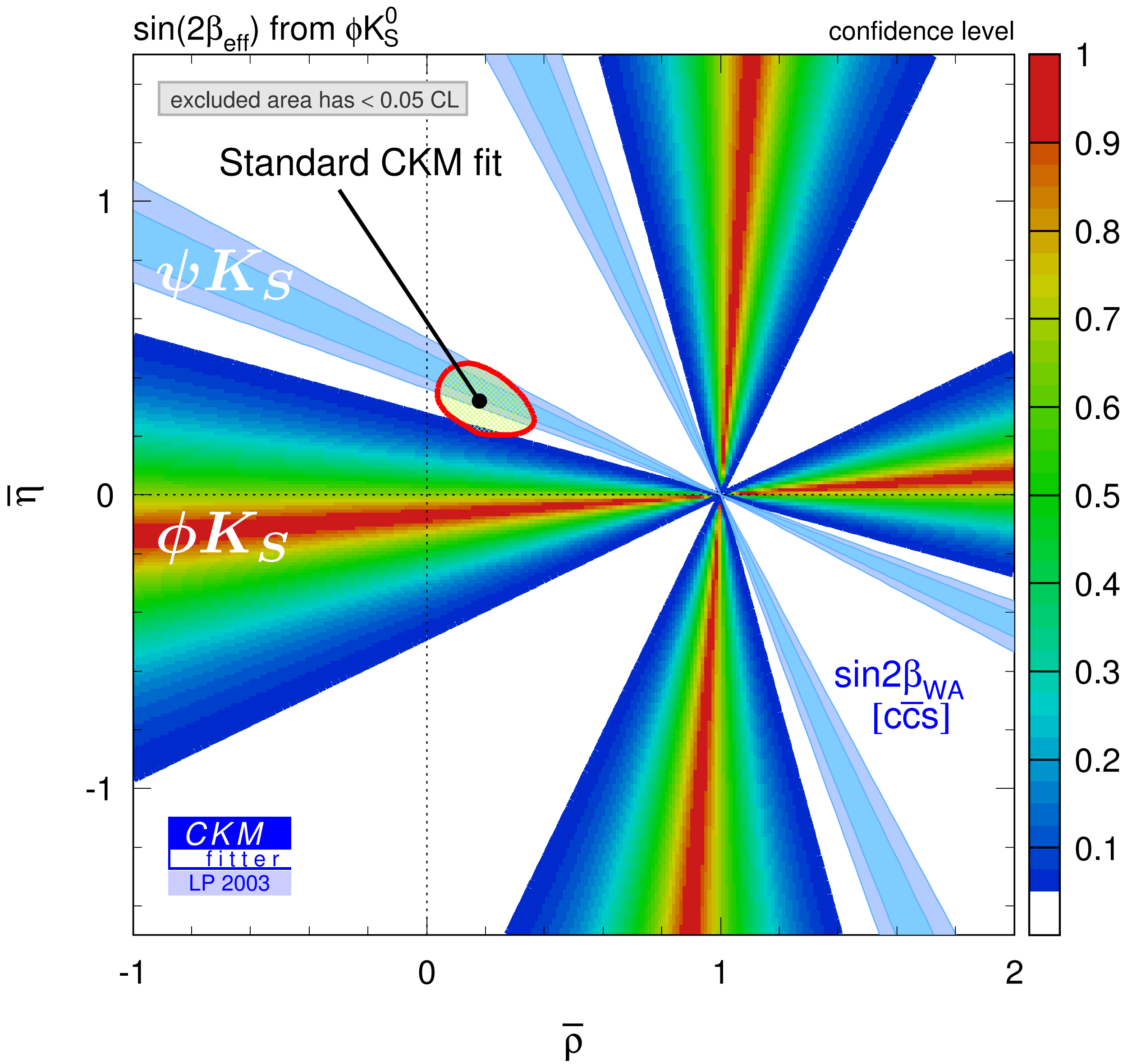
With NP: $S_{\phi K_S} \neq S_{\psi K}$ possible

ψK_S: NP could enter through mainly mixing

ϕK_S: NP could enter through both mixing and decay

- Measuring the same angle (β) in different decays may be the best way to find NP

CPV in ϕK_S: present status



BABAR and BELLE:

$$S_{\psi K}^{(\mathrm{WA})} = 0.739 \pm 0.048$$

$$S_{\phi K}^{(\mathrm{BABAR})} = 0.45 \pm 0.43$$

$$S_{\phi K}^{(\mathrm{BELLE})} = -0.96 \pm 0.51$$

$$S_{\phi K}^{(\mathrm{WA})} = -0.14 \pm 0.33$$

$\Rightarrow$ 2.7σ deviation from SM

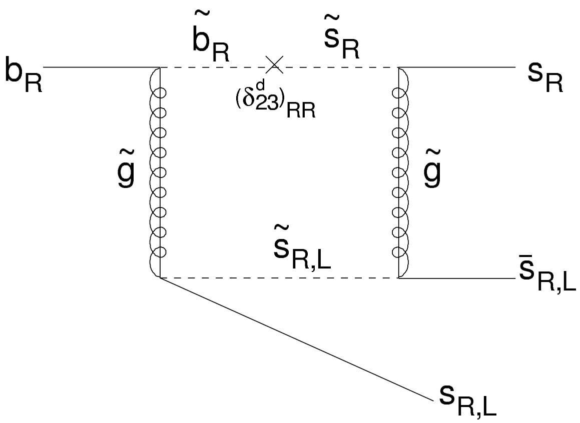
ϕK_S and SUSY GUTs

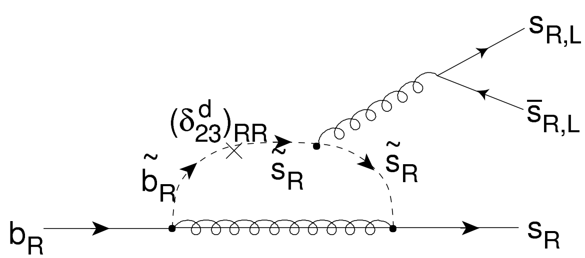
[Harnik, Larson, Murayama, Pierce]

Near maximal $\nu_\mu - \nu_\tau$ mixing may imply large mixing between s_R and b_R, and between $\tilde{s}_R$ and $\tilde{b}_R$

$$\begin{pmatrix} \tilde{s}_R \\ \tilde{s}_R \\ \tilde{s}_R \\ \tilde{\nu}_\mu \\ \tilde{\mu} \end{pmatrix} \longleftrightarrow \begin{pmatrix} \tilde{b}_R \\ \tilde{b}_R \\ \tilde{b}_R \\ \tilde{\nu}_\tau \\ \tilde{\tau} \end{pmatrix}$$

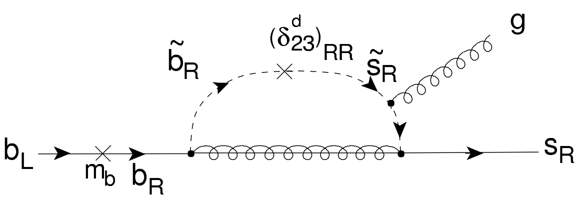
Mixing among right-handed quarks drop out from CKM matrix, but among right-handed squarks it is physical

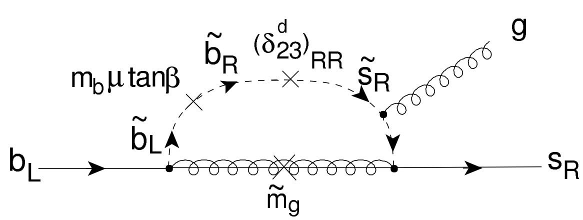




$\mathcal{O}(1)$ effects in $b \to s$ possible

$$O'_{3\ldots6} = [\bar{s}\gamma^\mu P_R (T^a) b] \times [\bar{s}\gamma_\mu P_{L,R} (T^a) s]$$

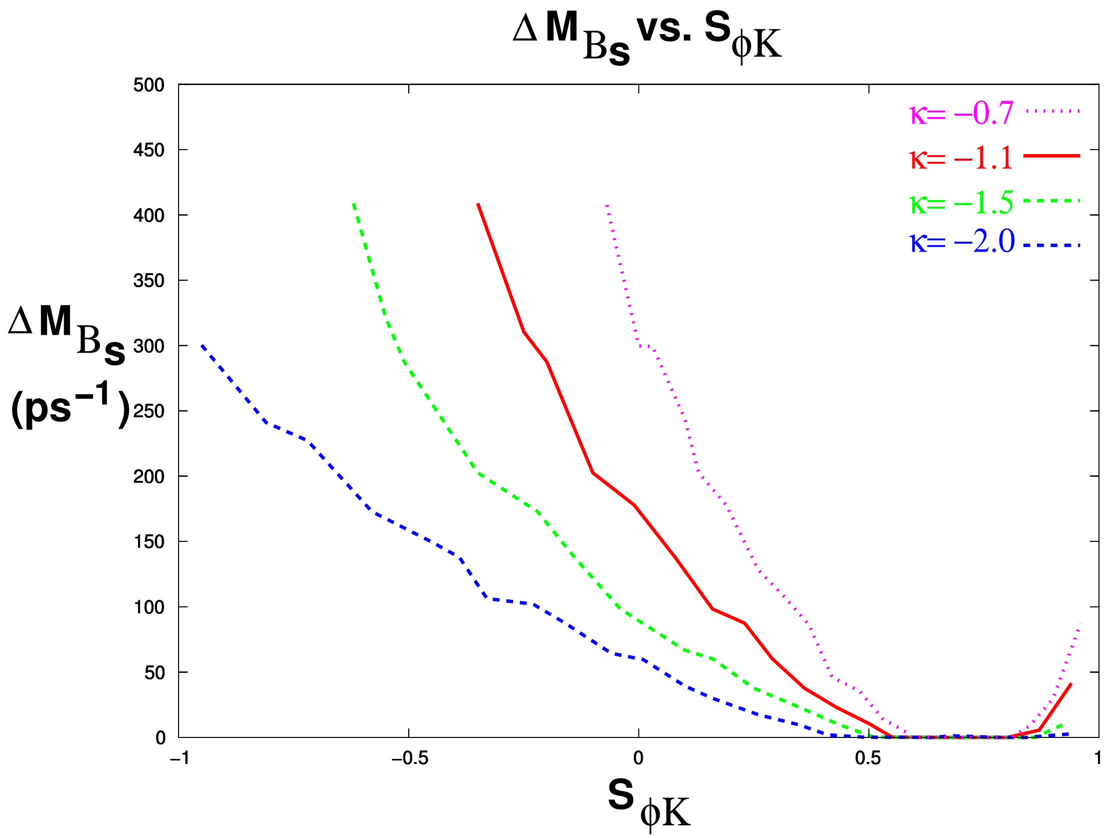




$$O'_8 = \frac{g_s}{16\pi^2}\, m_b \,(\bar{s}\, \sigma_{\mu\nu} G^{\mu\nu} P_L\, b)$$

Possible implications

- Modify CP violation in $B_d \to \phi K_S$ [SM: $\sin 2\beta + \mathcal{O}(\lambda^2)$]
- Sizable CP violation in $B_s \to \psi\phi$ [SM: $\mathcal{O}(\lambda^2)$]
- B_s mixing may be much faster than in SM — not observable at CDF / LHCb / BTeV



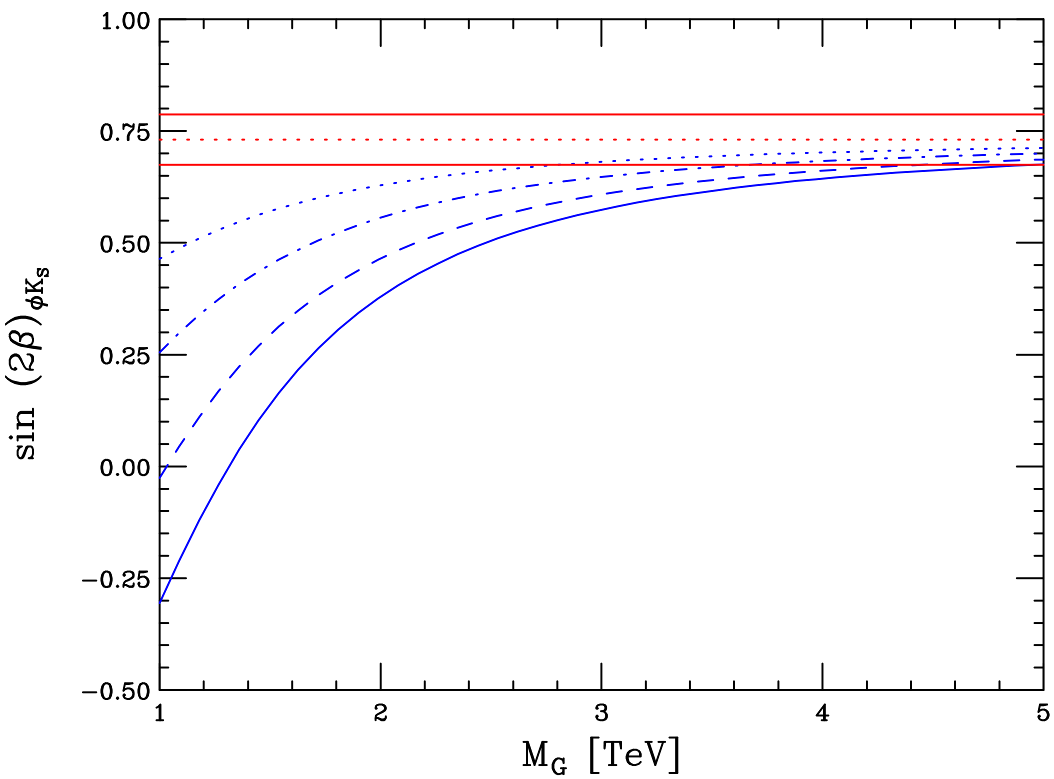
Do mixing of quarks and leptons have common origin?

ϕK_S and extra dimensions

[Burdman]

Tree-level FCNC due to non-universal quark couplings to few-TeV gauge bosons

E.g.: warped extra dimensions with bulk gauge fields and fermions (localized at different positions in bulk): lightest KK-gluon [also in topcolor models: top-gluon]



$$\mathcal{L} = -\frac{4\pi\alpha_s}{M_G^2}\, D_L^{bs} (\bar{s}_L\gamma^\mu T^a b_L)(\bar{s}\gamma_\mu T^a s)$$

assume $D_L^{bs} = V_{tb}^* V_{ts}\, e^{i\omega}$

curves are for unknown phase $\omega = \pi/3,\ \pi/4,\ \pi/6,\ \pi/10$

Also predicts large enhancement of Δm_{B_s}, effects in $b \to s\ell^+\ell^-$, etc.

ϕK_S and the Standard Model

Earlier, I had a simplified picture... the full amplitude is:

$$A = \overset{\mathcal{O}(\lambda^2)}{V_{cb}^* V_{cs}} \left[P_c - P_t + T_{c\bar{c}s}\right]$$

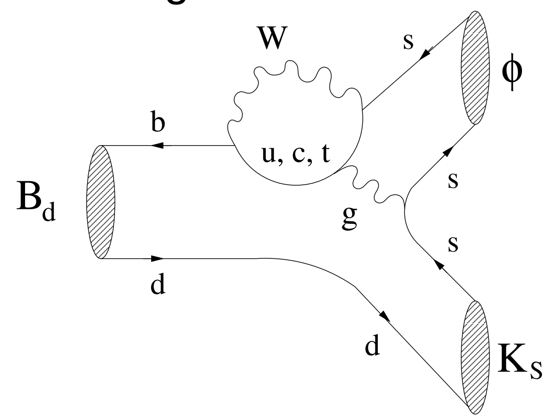
dominant contribution

$$+ \overset{\mathcal{O}(\lambda^4)}{V_{ub}^* V_{us}} \left[P_u - P_t + T_{u\bar{u}s}\right]$$

suppressed by λ^2

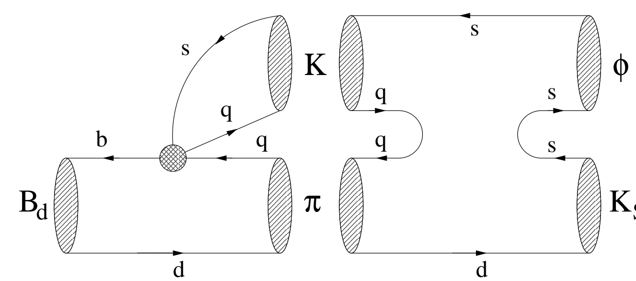
$+$ **New Physics?**

"Penguin:"



So far we considered 3rd line vs. 1st line; but it is the 2nd line that limits the sensitivity to new physics

"Rescattering:"



How large should $S_{\phi K_S} - \sin 2\beta$ be, so that it is definitively due to new physics?

Constraining the SM pollution

[Grossman, ZL, Nir, Quinn]

- How large can the second, CKM suppressed, term be?

$$A_f = \overset{\mathcal{O}(\lambda^2)}{V_{cb}^* V_{cs}}\, a_f^c + \overset{\mathcal{O}(\lambda^4)}{V_{ub}^* V_{us}}\, a_f^u = V_{cb}^* V_{cs}\, a_f^c\, (1 + \xi_f) \qquad \text{[expect } |\xi_f| = \mathcal{O}(\lambda^2);\ f = \phi K_S]$$

$$\Rightarrow\ S_{\phi K_S} - \sin 2\beta = 2\cos 2\beta\, \sin\gamma\, |\xi_f|\, \cos\arg(a_f^u / a_f^c)$$

$|\xi_f|$ depends on unknown hadronic matrix elements

Constrain it using $SU(3)$ flavor symmetry and data on $b \to q\bar{q}d$ transitions:

$$A_{f'} = V_{cb}^* V_{cd}\, b_{f'}^c + V_{ub}^* V_{ud}\, b_{f'}^u = V_{ub}^* V_{ud}\, b_{f'}^u\, (1 + \lambda^2 \xi_{f'}^{-1})\,, \qquad a_f^u = \sum_{f'} x_{f'}\, b_{f'}^u$$

Obtain bounds of the form:

$$|\xi_f| \equiv \left| \frac{V_{ub}^* V_{us}}{V_{cb}^* V_{cs}}\, \frac{a_f^u}{a_f^c} \right| < \left| \frac{V_{us}}{V_{ud}} \right| \sum_{f'} |x_{f'}| \sqrt{\frac{\mathcal{B}(f')}{\mathcal{B}(f)}}$$

Bounds on CPV in ϕK_S

- Many invariants under $SU(3)$ — messy relations: $(s \equiv \sin\theta_{\eta\eta'},\, c \equiv \cos\theta_{\eta\eta'})$

$$a(\phi K^0) = \frac{1}{2}\left[b(\overline{K^{*0}}K^0) - b(K^{*0}\overline{K^0})\right] + \frac{1}{2}\sqrt{\frac{3}{2}}\left[cb(\phi\eta) - sb(\phi\eta')\right]$$
$$+ \frac{\sqrt{3}}{4}\left[cb(\omega\eta) - sb(\omega\eta')\right] - \frac{\sqrt{3}}{4}\left[cb(\rho^0\eta) - sb(\rho^0\eta')\right]$$
$$+ \frac{1}{4}b(\rho^0\pi^0) - \frac{1}{4}b(\omega\pi^0) - \frac{1}{2\sqrt{2}}b(\phi\pi^0)$$

No bound on $\xi_{\phi K_S}$ using only $SU(3)$ at present (no useful exp. bound on $K^{*0}\overline{K^0}$)

Charged modes: $a(\phi K^+) = b(\phi\pi^+) + b(\overline{K^{*0}}K^+)$

Need dynamical assumption ($|a^u_{\phi K^0}| \not> |a^u_{\phi K^+}|$) to use this bound $\Rightarrow |\xi_{\phi K_S}| < 0.25$

- Weaker bounds than other estimates in the literature, but less model dependent
  With more data they will get significantly stronger

Summary: ϕK_S

New physics could show up naturally in $S_{\phi K_S} - S_{\psi K_S}$
Sensitivity not limited in an essential way by hadronic uncertainties for a long time

It is not obvious that ϕK_S is the best mode to control hadronic uncertainties
Worth studying others: $\eta' K_S$, $\pi^0 K_S$, and some not yet measured ones

Interaction between theory and experiment is crucial — with more data we often find new ways to get rid of hadronic uncertainties

When new phenomena are seen at the LHC, "low energy high energy physics" may be crucial to understand what the new phenomena are, and what they are not